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Evaluating the Impact of Structural Breaks on the Nexus between Natural Gas Investment and Economic Growth: Evidence from Nigeria

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ABSTRACT: This study examines the impact of structural breaks on the relationship between natural gas production and economic growth in Nigeria, with a focus on the 2010 policy reforms. Utilizing the Autoregressive Distributed Lag (ARDL) model, the analysis incorporates structural breaks to assess their influence on the natural gas-economic growth nexus. Two models were estimated: One model assumed a single structural break in 2010, and the other introduced dummy variables to isolate the effects of structural changes. The findings indicate that the model that explicitly accounts for structural shifts using dummy variables provides a more robust explanation, demonstrating higher explanatory power and superior model fit.The results confirm that the 2010 policy changes significantly shaped the gas sector's contribution to economic growth, emphasizing the need for policymakers to consider structural shifts in economic planning. The study underscores the importance of sustained investment in gas infrastructure, phased policy implementation to minimize economic volatility, and incentives to attract private sector participation. Additionally, economic diversification remains crucial for reducing reliance on the energy sector and mitigating risks associated with structural disruptions.Overall, this study highlights the necessity of integrating structural breaks into economic modelling to enhance policy formulation and support sustainable economic growth in Nigeria.

KEYWORDS: Natural Gas Production, Economic Growth, Structural Breaks, ARDL model, Policy Reforms, Gas Infrastructure, Economic Diversification, Nigeria

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I. INTRODUCTION

Nigeria's economy heavily depends on its natural gas sector, which contributes significantly to energy supply, foreign exchange earnings, and industrial growth[1]. While existing literature acknowledges the positive link between energy production and economic development [2], Despite the sector's importance, the relationship between natural gas production and economic growth remains dynamic due to economic shocks, regulatory changes, and external market forces [3]. Nigeria has experienced major policy shifts in the oil and gas sector, including the Petroleum Industry Act (PIA) of 2021, fluctuations in global gas prices, and disruptions due to economic crises, all of which may introduce structural breaks in time series data [4]. Structural breaks can lead to spurious regression results and inaccurate economic inferences [5].

Given Nigeria's dynamic energy landscape, it is imperative to assess how structural breaks influence the nexus between natural gas production and economic growth. This study applies econometric methods to detect and correct structural breaks in time-series data, thereby enhancing the robustness of empirical findings. By doing so, it provides deeper insights into the long-run sustainability of Nigeria's natural gas sector as a driver of economic growth.

Natural gas production is significant in economic development, particularly in energy-dependent economies such as Nigeria. As a cleaner alternative to crude oil, natural gas enhances industrial productivity, supports electricity generation, and attracts foreign investment [6]. The linkage between natural gas production and economic growth is often analyzed within the broader energy-growth nexus, which suggests that energy availability fosters industrial expansion and economic development [2].

II. LITERATURE REVIEW

Conceptual Framework

Structural breaks refer to sudden changes in economic relationships due to shifts in policy, external shocks, or technological advancements [5]. Ignoring structural breaks in time-series analysis can lead to biased estimations and incorrect inferences about causal relationships [7]. Structural breaks are particularly relevant in Nigeria, where economic reforms, policy adjustments, and fluctuations in global energy markets have led to changes in macroeconomic dynamics.

To mitigate the effects of structural breaks, econometric models often incorporate dummy variables that account for changes in economic behaviour over time. Interactive dummy variables allow researchers to analyze how relationships between key economic variables evolve before and after a structural shift [8]. This approach enhances model accuracy by capturing dynamic interactions that simple regression models may overlook.

Theoretical Framework

The Endogenous growth theory posits that investment in productive sectors, such as energy infrastructure, leads to sustained economic growth [9]. Gas production investment enhances industrial productivity, increases employment, and attracts foreign direct investment (FDI), ultimately boosting economic output [10]. This theory underpins the study's assumption that natural gas infrastructure investment drives Nigeria's economic growth.

The resource-based theory suggests that a country's economic performance depends on effectively utilising its natural resources [11]. While Nigeria has vast natural gas reserves, its economic benefits depend on policies encouraging gas production and utilization [12]. This theory supports the study's focus on assessing the long-term contribution of gas production to GDP.

Structural change theory highlights the role of industrial transformation in economic development [13]. As countries transition from primary resource dependence to industrialization, investments in energy infrastructure play a critical role in sustaining growth [14]. Structural breaks in Nigeria's economic data often reflect policy-induced transformations in the energy sector.

Empirical Review

Empirical studies on the relationship between natural gas production and economic growth have yielded mixed findings. Apergis and Payne [10] conducted a panel study across emerging economies and found a bidirectional causality between gas consumption and GDP.

Similarly, Tsangyao Chang, Rangan Gupta, Roula Inglesi-Lotz, and Beatrice D. Simo-Kengne [15] examined the link between natural gas consumption and economic growth in G7 countries from 1965 to 2011. Using the Granger causality procedure, the study finds that there is no significant causal relationship between natural gas consumption and economic growth for the panel of G7 countries. However, individual country results vary. Since the relationship between natural gas consumption and economic growth varies by country, energy policies should be tailored to each nation's specific economic and energy contexts.

Akos Losz and Jonathan Elkind[16] discussed the potential of natural gas as a bridge fuel in transitioning to a low-carbon energy system. It highlights the environmental benefits of natural gas, such as its superior air quality attributes compared to coal and oil.

Elizabeth Sendich[17] highlights the critical role of natural gas in supporting industrial growth, particularly in energy-intensive sectors. The study examines how natural gas serves as a fuel source and a feedstock in industries such as chemicals, steel, and manufacturing.Sendich emphasizes natural gas's economic and environmental advantages, including cost efficiency and lower emissions compared to other fossil fuels. The article also discusses market trends, price fluctuations, and policy implications, illustrating the strategic importance of natural gas in industrial sustainability and competitiveness.

Solarin and Shahbaz (2015). [18] investigated the relationship between natural gas consumption and economic growth in Malaysia from 1971 to 2012. The study incorporates foreign direct investment (FDI), capital formation, and trade openness into the analysis. Using structural break unit root tests and cointegration techniques, the authors find that natural gas consumption, FDI, capital formation, and trade openness positively influence economic growth. The results support the feedback hypothesis, indicating bidirectional causality between these variables and economic growth. The study underscores the importance of

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strategic policies to harness these factors for sustainable growth

Structural breaks have been widely studied in economic modelling. Perron (1989) [7] introduced break-point analysis, arguing that ignoring breaks leads to spurious regression results. Bai and Perron (2003) [5] developed multiple structural break tests to improve time-series analysis accuracy. Recent studies apply the CUSUM and CUSUM of squares tests to detect stability changes in macroeconomic variables (Brown et al., 1975) [19]; Pesaran et al., (2001) [14].

Narayan and Popp (2010)[8] demonstrated that using dummy variables to address structural breaks improves econometric model reliability. Aydin (2019) [20] applied this method in an energy-growth analysis and found that the impact of gas production on GDP varies significantly before and after structural changes.

The ARDL approach has been widely used to study energy-growth relationships due to its ability to capture short- and long-term dynamics. Pesaran et al. (2001) [14] emphasized that ARDL is suitable for datasets with structural breaks, provided thatdummy variables are included to account for instability.

Mukhtar Danladi Galadima, Abubakar Wambai Aminu, Ibrahim Muhammad Adam, Ibrahim Mohammed Adamu, and Hassan Hassan Suleiman[21] used ARDL to investigate the short-term dynamics and long-term relationship between natural gas consumption and economic growth in Nigeria, incorporating structural breaks. The results reveal a positive and significant long-term relationship between natural gas consumption and economic growth, with evidence of bidirectional causality in the long term.

III. MATERIAL AND METHODS

Data and Variables

This study employs annual time-series data from 2000 to 2022 from the Central Bank of Nigeria (CBN), the World Bank, Organization of Oil Exporting Countries (OPEC), and the Nigerian National Petroleum Corporation (NNPC). The key variables include Gross Domestic Product (GDP) as the dependent variable, Gas Production output as the independent Variable, and foreign direct investment (FDI) and Industrial output as control Variables.

Methodology

ARDL Model Specification

Specifying the ARDL in line with the works of Pesaran et al. 1999 [22],where p, q, and r represent the lag lengths for the dependent and independent variables, respectively.

$$Y_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i Y_{t-i} + \sum_{j=0}^{q} \beta_j G_{t-j} + \sum_{k=0}^{r} \gamma_k X_{t-k} + \ \dots \ + \epsilon_t \qquad (1)$$

Where:

Y_t, = the dependent variables lagged by i period.

G_{t-j} = independent variables lagged by j period

X_{t-k} = control variables lagged by k period

(α_i), (β_j) and (γ_k) = the coefficients of the lagged variables.

X_t = Represents control variables

(ϵ_t) = is the error term.

Structural Break Detection

To examine the stability of the relationship between natural gas production and economic growth, we employ the CUSUM and CUSUM of squares tests (Brown et al., 1975). These tests help identify structural breaks in the regression model, which may be attributed to economic reforms, global financial crises, or fluctuations in gas prices.

Handling Structural Breaks Using Dummy Variables

Once structural breaks are detected, dummy variables (D) are introduced to account for the breakpoints, while interactive dummy variables, which are the interaction terms of the dummy variable and the regressors (D × X), are used to capture changes in the relationship between the independent and dependent variables [8]. This method allows for a more accurate estimation of the impact of gas production on economic growth before and after structural shifts.

The re-specified ARDL equation to account for the effect of the structural break for the model is shown below.

$$Y_t = \alpha_0 + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=0}^{q} \gamma_j X_{t-j} + \delta_0 D_t + \delta_1 (D_t * X_{t-j}) + \epsilon_t \ (2)$$

Where:
$D_t =$ Dummy variable capturing the structural break.
δ_0 = captures changes on the intercept and represents the magnitude of the shift due to the break.
δ_1 = captures changes in the slope.
$(D_t * X_{t-j})$= interaction term captures the differential effect of X_t in the post-break

IV RESULTS AND DISCUSSION

Descriptive Statistics

From Table 1, The Jarque-Bera test assesses normality in data distribution. The probability values for all variables (ranging from 0.33 to 0.76) are above 0.05, indicating that the variables do not significantly deviate from a normal distribution. This suggests that the data is approximately normally distributed.

Table 1 Descriptive Statistics Result

	GDP	GAS_PROD	FDI	GFCF	IND_OUT
Mean	333.0534	34194.11	3.93087	53.91435	32.87435
Median	375.7457	38411	3.31	56.91	29.72175
Maximum	574.1838	49947.29	8.84	88.11	64.40968
Minimum	69.17145	12460	-0.19	24.78	9.637935
Std. Dev.	156.9997	12197.16	2.616712	17.4898	17.59244
Skewness	-0.450042	-0.392306	0.442	-0.153913	0.37223
Kurtosis	1.895209	1.700859	2.115407	2.320654	1.927141
Jarque-Bera	1.946103	2.207409	1.498794	0.53309	1.634195
Probability	0.377928	0.33164	0.472651	0.766021	0.441712
Sum	7660.228	786464.5	90.41	1240.03	756.1101
Sum Sq. Dev.	542275.7	3.27E+09	150.638	6729.651	6808.867
Observations	23	23	23	23	23

Source: EViews 12

Time Series Plots

The stylized fact presented in the graph in Figure 1 which illustrates the trends in Nigeria's economic indicators, including Gross Domestic Product (GDP), Gas Production (Gas_Prod), Foreign Direct Investment (FDI), Gross Fixed Capital Formation (GFCF), and Industrial Output (Ind_Out), over the years 2001 to 2022. The chart also highlights key global and domestic events that have significantly influenced these economic variables.

From the early 2000s, GDP and gas production exhibited steady growth, reflecting Nigeria's economic expansion and increased exploitation of natural gas resources. However, the 2008 Global Financial Crisis, marked by the blue vertical band, disrupted this trend, leading to a decline in GDP and FDI. Despite this setback, the implementation of the Niger Delta Amnesty Program and the Nigeria Gas Master Plan (highlighted in yellow) around 2009 played a crucial role in stabilizing gas production and boosting economic activities by reducing militant disruptions in the oil and gas-producing region.

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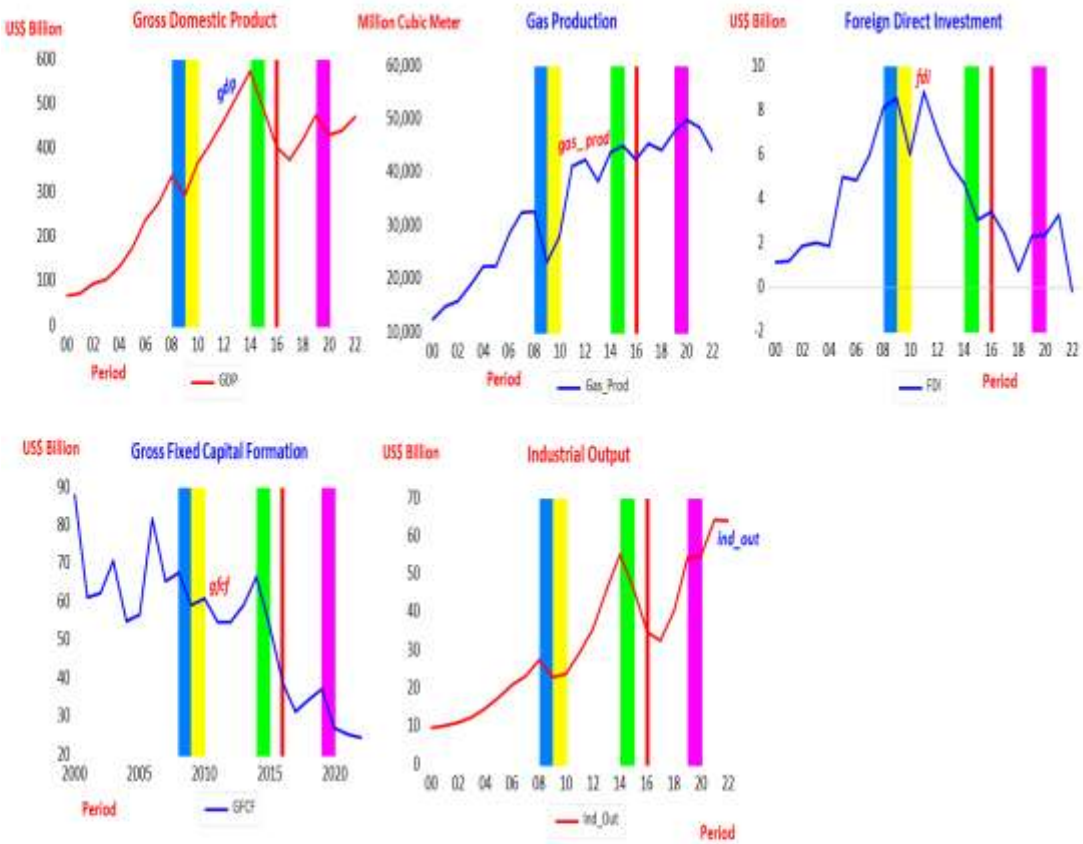

Figure 1 Annual Trend of the Interactions of key Control Variables with Gas Production and GDP in Nigeria

Between 2010 and 2014, GDP and gas production continued to rise, coinciding with relative economic stability and increased investment in gas infrastructure. However, the US Shale Oil Price Shock in 2014 (green band) resulted in a significant decline in global oil and gas prices, impacting Nigeria's gas revenue and leading to a decline in GDP and industrial output. The effects of this shock culminated in Nigeria's Economic Recession in 2016 (marked by the red vertical line), which saw a sharp decline in GDP and gas production. This period also witnessed a downturn in FDI and GFCF, indicating reduced investor confidence.

Following the recession, GDP and gas production gradually recovered, but the economy faced another major shock in 2020 due to the COVID-19 Pandemic (pink band). This led to a contraction in GDP and a temporary decline in gas production, reflecting the global economic slowdown and reduced industrial activity. However, post-pandemic, GDP and gas production showed signs of recovery, albeit at a slower pace compared to pre-2016 levels.

Throughout the period, FDI remained relatively low and volatile, suggesting persistent challenges in attracting foreign investment. Despite increased gas production, industrial output and GFCF also displayed limited growth, indicating structural constraints in Nigeria's industrial sector. This trend supports concerns about the limited impact of gas production on industrial development and economic diversification.global economic shocks, domestic policy interventions, and Nigeria's economic performance. It underscores Nigeria's economy's vulnerabilities to external shocks, particularly fluctuations in global energy markets, and the need for strategic policies to enhance the linkages between gas production, industrial output, and overall economic growth.

The graph highlights the complex interplay between global economic shocks, domestic policy interventions, and Nigeria's economic performance. It underscores Nigeria's economy's vulnerabilities to external shocks, particularly fluctuations in global energy markets, and the need for strategic policies to enhance the linkages between gas production, industrial output, and overall economic growth.

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ARDL Model Specification

Below is the specified ARDL Model following the works of Pesaran et al., 1999, and Pesaran et al., 2001.

$$GDP_t = \alpha_0 + \sum_{i=1}^{p} \beta_0 \, GDP_{t-i} + \sum_{j=0}^{q1} \beta_{1_j} Gas\_PROD_{t-j} + \sum_{j=0}^{q2} \beta_{2_j} FDI_{t-j} + \sum_{j=0}^{q3} \beta_{3_j} GFCF_{t-j} + \sum_{j=0}^{q4} \beta_{4_j} Ind\_Out_{t-j} + \square_t \quad (4)$$

Where:
GDP= Gross DomesticProduct
GAS_PROD = Gas Production Output in billions of cubic meters
FDI = Foreign Direct Investment in US Million
GFCF = Gross Fixed Capital Formation in US billion
IND_OUT = Industrial Output in US billion
α_0 = Constant term
j, p, $q_1, q_2, q_3, \ldots, q_9$ = lag order of variables
$\square_t$ = Error term

To enhance the efficacy of the assessment and mitigate serial correlation and heteroskedasticity in the specified model a logarithmic function was employed to transform the model, as demonstrated below:

$$LOG\_GDP_t = \alpha_0 + \sum_{i=1}^{p} \beta_0 \, LOG\_GDP_{t-i} + \sum_{j=0}^{q1} \beta_{1_j} LOG\_GAS\_PROD_{t-j} + \sum_{j=0}^{q2} \beta_{2_j} LOG\_FDI_{t-j} +$$

Where:
LOG_GDP= Natural Log of Gross Domestic Product
LOG_GAS_PROD = Natural Log of Gas Production Output in billions of cubic meters
LOG_FDI = Natural Log of Foreign Direct Investment in US billion
LOG_GFCF = Natural Log of Gross Fixed Capital Formation in US billion
LOG_IND_OUT = Natural Log of Industrial Output in US billion
α_0 = Constant term
j, p, $q_1, q_2, q_3, \ldots, q_9$ = lag order of variables
$\square_t$ = Error term

Unit Root Test

The Augmented Dickey-Fuller (ADF) unit root test was used to test whether the variables were stationary and their order of integration. The ADF has the advantage of correcting serial correlation in the variable. The result of the ADF unit root of the test is shown in Table 2.

The Results of ADF tests shows that all variables are non-stationary except Ind_Out, which is stationary at levels. Results from the ADF tests also show that all the non-stationary series became stationary in first differences with a 5% significance level. So, the individual series are found to be integrated of order I (0) and I(1)

Table 2 Result of Unit Root Test

Augmented Dickey-Fuller (ADF) Test				**AIC Criterion**		
Variables		**Level**		**First Difference**		**Stationarity Status**
		C	**C&T**	**C**	**C&T**	
Gas_Prod	ADF t-stat	2.5737	0.3600	4.6224***		I(I)
	TCV (5% Level)	3.004861	3.6584	3.0124		
GDP	ADF t-stat	1.498199	1.7429	3.3337**	3.4451*	I(I)

	TCV (5% Level)	3.004861	3.6450	3.0124	3.6450	
FDI	ADF t-stat	1.294583	1.3346	4.7829***		I(I)
	TCV (5% Level)	3.004861	3.6329	3.012363		
GFCF	ADF t-stat	1.795313	3.2706*	5.1539***		I(I)
	TCV (5% Level)	3.004861	3.6329	3.0207		
Ind_Out	ADF t-stat	0.937157	4.1192**	4.0384***		I(0)
	TCV (5% Level)	3.012363	3.6584	3.0300		
	TCV (5% Level)	3.004861	3.6329	3.0124		
Note:	• C – Intercept • C & T Intercept & Trend • AIC – Akaike Info Criterion • ***, ** and * indicate significance at 1%, 5% and 10% level of significance.					

Source: EViews 12

Optimal Lag Selection

To examine the long run cointegration between these variables, the order of lags that will be applied in the first differenced variables. As suggested by Pesaran et al. (2001), AIC was used to determine the optimum lag selection for the ARDL model. This was also be examined in the presence of the trend and without the trend. The Unrestricted Vector Autoregressive (UVAR) Lag Length Selection Criteria results give the optimal lag length of 1 and 2 for the variables, as in Table 3.

Table 3 ARDL distributed lag selection Results

Variables	**Criterion**							**Optimal Lag Order**
	Lag	**LogL**	**LR**	**FPE**	**AIC**	**SC**	**HQ**	
FDI	0	-49.2481	NA	7.012736	4.785533	4.835272	4.796328	
	1	**-39.71182**	**17.25612***	**3.111970***	**3.972554***	**4.072032***	**3.994143***	**1**
	2	-39.54021	0.294185	3.372112	4.051448	4.200666	4.083833	
GDP	0	-133.067	NA	7.012736	4.785533	4.835272	4.796328	
	1	**-108.976**	**43.59334***	**3.111970***	**10.56914***	**10.66862***	**10.59073***	**1**
	2	-108.1922	1.343643	3.372112	10.58973	10.73895	10.62211	
Gas_Prod	0	-80.26006	NA	134.4575	7.739053	7.788792	7.749848	
	1	**-68.64584**	**21.01621***	**48.9538***	**6.728175***	**6.827654***	**6.749765***	**1**
	2	-68.55883	0.149167	53.47515	6.815126	6.964344	6.84751	
GFCF	0	-88.11502	NA	284.1039	8.487145	8.536884	8.49794	
	1	**-76.81851**	**20.44131***	**106.6152***	**7.506524***	**7.606003***	**7.528114***	**1**
	2	-76.44238	0.644795	113.2991	7.565941	7.715158	7.598325	
Ind_Out	0	-88.55566	NA	296.2801	8.52911	8.578849	8.539905	
	1	-67.3636	38.34754*	43.32626	6.606057	6.705535*	6.627646	
	2	**-66.0961**	**2.172848**	**42.29513***	**6.580581***	**6.729799**	**6.612965***	**2**
	1	**-42.90672**	**48.68272***	**4.218722***	**4.276830***	**4.376309***	**4.298420***	

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	2	-42.62245	0.487322	4.522593	4.344995	4.494212	4.377379	
Note:	* indicates lag order selected by the criterion							
	LR: sequential modified LR test statistic (each test at 5% level)							
	FPE: Final prediction error							
	AIC: Akaike information criterion							
	SC: Schwarz information criterion							
	HQ: Hannan-Quinn information criterion							

Source: EViews 12

Structural Break Tests

The results from the CUSUM and CUSUM of squares (CUSUMQ) tests in Figures 2 and 3 indicate structural breaks in 2010, coinciding with policy changes in Nigeria's gas sector. These breaks justify the inclusion of dummy variables in the regression model. The results of the CUSUM stability test indicate residual stability since the CUSUM lines in Fig. 2 fell in-between the two 5 per cent lines of significance, while in CUSUMQ, the residual stability line (Fig.3) crosses the 5 per cent line of significance in 2011, indicating a structural break in model from 2010.

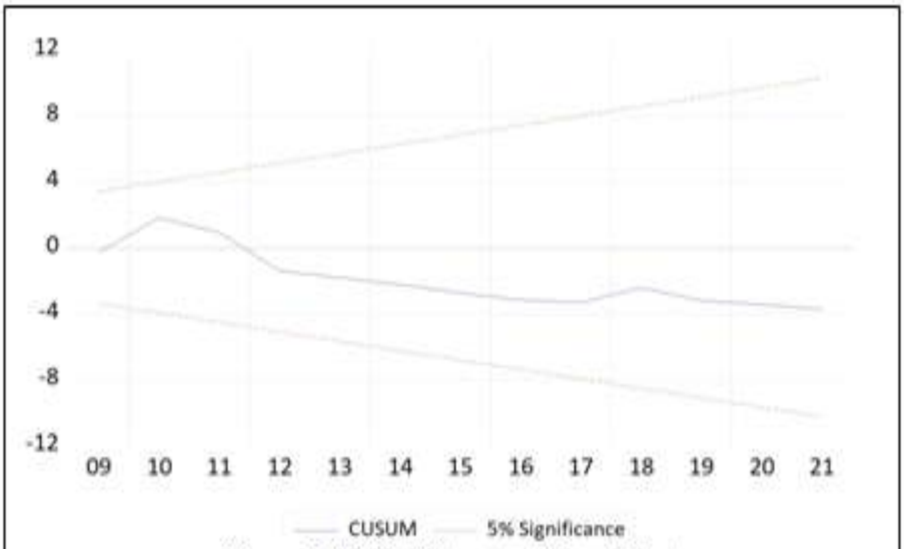

Figure 2 CUSUM Structural Break Test

The structural break in the time series data in Fig. 3 occurs against the backdrop of the implementation of the Nigeria Gas Master Plan (NGMP) in 2008, which marked a significant shift in Nigeria's natural gas policy landscape, targeting gas production stabilization, reduction of gas flaring, and industrial growth through enhanced infrastructure and policy reform. However, the effects of the NGMP became notably pronounced by 2010 and in addition to the Niger Delta amnesty program, both resulted in a structural break in the dynamics of gas production, industrial output, and economic growth.

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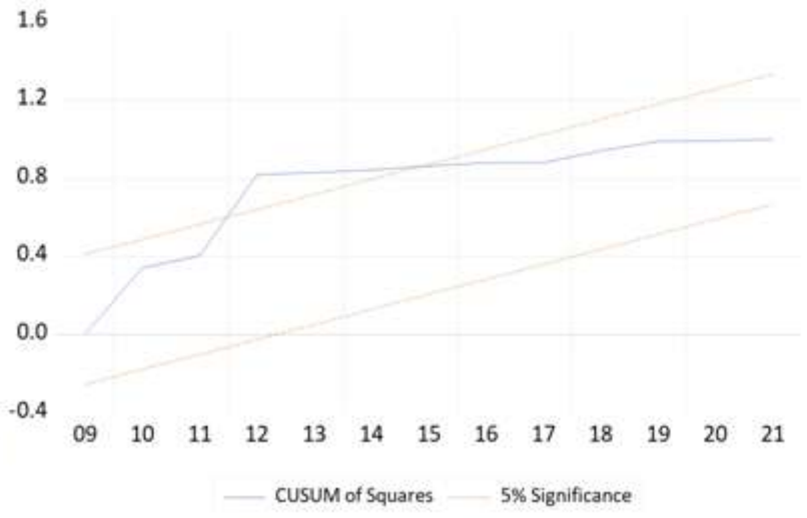

Figure 3 CUSUM of Squares Structural Break Test

The NGMP's emphasis on utilizing gas as a catalyst for economic diversification contributed to structural changes in Nigeria's economy. By redirecting gas resources towards non-oil industries, the NGMP laid the groundwork for long-term shifts in the composition of economic activities, further contributing to the structural break observed in 2010.

Modification of the Model to account for Structural Break

Re-specifying an econometric model with dummy variables is a straightforward and effective way to address structural breaks, whether they involve level shifts (changes in the intercept), slope changes (changes in the relationship between variables), or both. This method involves incorporating dummy variables into the regression model to represent changes in the data structure due to policy interventions, economic crises, or other events.

$$\mathbf{LOG\_GDP}_t = \alpha_0 + \sum_{i=1}^{p} \beta_0\, \mathbf{LOG\_GDP}_{t-i} + \sum_{j=0}^{q_1} \beta_{1_j} \mathbf{LOG\_GAS\_PROD}_{t-j} + \sum_{j=0}^{q_2} \beta_{2_j}\, \mathbf{LOG\_FDI}_{t-j} + \sum_{j=0}^{q_3} \beta_{3_j}\, \mathbf{LOG\_GFCF}_{t-j} + \sum_{j=0}^{q_4} \beta_{4_j}\, \mathbf{LOG\_Ind\_Out}_{t-j} + \sum_{j=0}^{q_5} \beta_{5_j}\, \mathbf{DUMMY\_2020}_{t-j} + \sum_{j=0}^{q_6} \beta_{6_j} \mathbf{LOG\_GAS\_PROD\_2010}_{t-j} + \sum_{j=0}^{q_7} \beta_{7_j}\, \mathbf{LOG\_FDI\_2010}_{t-j} + \sum_{j=0}^{q_8} \beta_{8_j}\, \mathbf{LOG\_GFCF\_2010}_{t-j} + \varepsilon_t \quad (6)$$

Where,
*Dummy*_2010= Dummy Variable at break point in 2010
LOG_GAS_PROD_2010 = Log of interaction of dummy of Gas
Production Output at break point in 2010
LOG_FDI_2010 = Log of the interaction of dummy of FDIat break point in 2010
LOG_GFCF_2010 = Log of the interaction of dummy of GFCF at break point in 2010

ARDL Model Estimation and Impact of Structural Breaks

Given that the research focuses on evaluating the impact of the structural breaks in this nexus, assessing whether the model with

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structural break effects enhances the model's explanatory power or whether a model with interactive dummy variables better captures the economic dynamics over time is essential.We conducted a comparative analysis of the two models to perform this analysis. Model 1 is the ARDL model with a structural break in 2010, as shown in equation (5), while Model 2 is the ARDL model with the interactive dummy variables, as shown in equation (6).

The statistical implications of the ARDL estimation results for Models 1 and 2 provide significant insights into the impact of structural breaks on the relationship between natural gas production and economic growth in Nigeria.

ARDL Bound Test

The calculated f-statistic was used to test for the joint significance of the derived coefficients of the specified lagged variables of models 1 and 2, which was done by comparing them with the upper and lower bound asymptotic critical value of f-statistics as provided by Pesaran et al. (2001) [14], as explained and presented in Table 4.

The F-bounds test results indicate that Model 2 provides stronger evidence of a long-run relationship between GDP and its explanatory variables. The calculated F-statistic for Model 2 (14.9390) far exceeds the upper bound critical values at all significance levels, confirming robust cointegration. In contrast, Model 1 reports an F-statistic of 4.6887, which only marginally exceeds the upper bound at the 5% significance level. This suggests that Model 1 provides moderate but weaker evidence of a stable long-run relationship than Model 2. Therefore, Model 2 presents a more robust confirmation of long-run equilibrium, suggesting that incorporating interactive dummy variables captures structural shifts more effectively than imposing a structural break.

Table 4 ARDL Bound Test Result

F-Bounds Test		**Null Hypothesis:** No levels Relationship			
Model	**F-Statistics**	**Signif.**	**I(0)**	**I(1)**	**Cointegration?**
Model 1	4.6887	5%	2.55	3.68	Yes***
Model 2	14.9390	5%	2.43	3.56	Yes***
*** 1%, 5% and 10% Significance Level					

Source: EViews 12

Residual Diagnostics Test

Having found cointegration in ARDL equation 5 (Model 1) and ARDL equation 6 (Model 2), Normality, serial correlation, Heteroskedasticity, and stability tests were applied to the two ARDL model specifications, from which the long-run and short-run coefficients will be derived. The test results for these models are summarised in Tables 5, 6, and 7 and Figures 4, 5, 6& 7, respectively.

1. Histogram Normality Test

Figures 4, 5, and Table 5 present the histogram for the residuals of the results of models 1 and 2. The Jarque-Bera test statistic for model 1 is 2.3399, with a corresponding probability value of 0.31039, while model 2 has a Jarque-Bera test statistic of 5.6472 at a p-value of 0.05939.

Since the p-values for both models are above the conventional significance level of 0.05, the null hypothesis of normality cannot be rejected. Statistically, this suggests that the residuals of the models are reasonably close to being normally distributed, which supports the validity of the model's results under the assumption of normality.

Table 5 Histogram Normality Test

Histogram Normality Test				
Null Hypothesis: Data are Normally Distributed				
Model	**Jarque-Bera**	**Probability**	**Signif. @ 5% Level**	**Normality Status**
Model 1	2.3399	0.31039	P > 0.05	Residuals are Normally Distributed
Model 2	5.6472	0.05939	P > 0.05	Residuals are Normally Distributed

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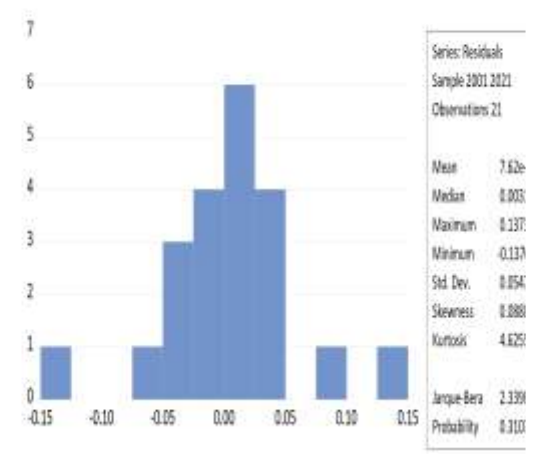

Figure 4 Histogram- Normality Test for Model 1

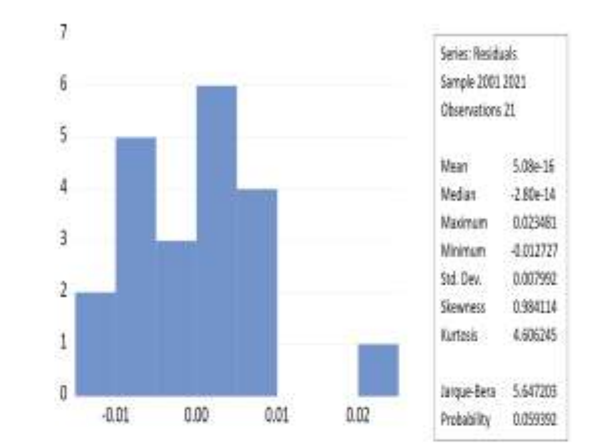

Figure 5 Histogram- Normality Test for Model 2

2 Breusch-Godfrey Serial Correlation LM Test:

Find below in Table 6 the result of Serial correlation testsfor determining the presence of autocorrelation among residuals for the ARDL models 1 and 2.The Breusch-Godfrey Serial Correlation LM Test results for Models reveal mixed findings regarding serial correlation. the F-statistic for model 1 is 3.711013with a corresponding p-value of 0.0587, while model 2 is 9.289301 at a p-value of 0.226. Since the p-values for both models exceed the 5% significance level, the null hypothesis of no serial correlation cannot be rejected, indicating any significant evidence of serial correlation based on this metric. However, for both models, the p-values of the Obs*R-squared statistic is below the 5% threshold, suggesting significant evidence of serial correlation in the residuals.

To reconcile these results and ensure robust conclusions, The Durbin-Watson (DW) test was employed as an additional diagnostic to check for autocorrelation in the residuals of both models. The DW statistic ranges from 0 to 4, where a value of 2 indicates no autocorrelation. The DW statistics for model 1 (1.899957) and model 2 (3.00457) are near 2, indicating that the residuals are likely independent and free from significant autocorrelation, satisfying this key diagnostic criterion for model reliability.

Table 6 ARDL BG Serial LM Test for Model 1 and Model 2

Breusch-Godfrey Serial Correlation LM Test:						
Null hypothesis: No serial correlation at up to 2 lags						**Serial Correlation Status**
Model 1	F-statistic	3.711013	Prob. F(2,11)		0.0587	No
	Obs*R-squared	8.460662	Prob. Chi-Square(2)		0.0145	Yes
	Durbin Watson	1.899957				No
Model 2	F-statistic	9.289301	Prob. F(2,1)		0.226	No
	Obs*R-squared	19.9274	Prob. Chi-Square(2)		0.00000	Yes
	Durbin Watson					

Source: EViews 12

3 HeteroskedasticityTest: Breusch-Pagan-Godfrey

Find in Table 7 the result of the Breusch-Pagan-Godfrey Heteroskedasticity test of the residuals for ARDL equation 5 (Model 1) and equation 6 (Model 2). The Breusch-Pagan-Godfrey test was employed to assess heteroskedasticity, which occurs when the varianceof residuals is not constant. The null hypothesis assumes homoskedasticity (constant variance). the F-statistic for model 1 is 0.7308 (p = 0.6502), and the Obs*R-squared is 5.93012 (p = 0.5479) while model 2 has F-statistic of 0.31058 (p = 0.951), and the Obs*R-squared is 13.39118 (p = 0.7096). All p-values are significantly greater than 0.05, indicating failure to reject the null hypothesis of homoskedasticity. This confirms that the residuals exhibit constant variance, meaning heteroskedasticity the model satisfies the assumption of homoskedasticity, ensuring the reliability of standard errors and statistical inferences.

Table 7 Heteroskedasticity Test: Breusch-Pagan-Godfrey

Heteroskedasticity Test: Breusch-Pagan-Godfrey						
Null hypothesis: Homoskedasticity						**Homoscedasticity Status**
Model 1	F-statistic	0.730807	Prob. F(7,13)		0.6502	Yes
	Obs*R-squared	5.930157	Prob. Chi-Square(7)		0.5479	Yes
	Scaled explained SS	4.119674	Prob. Chi-Square(7)		0.7659	
Model 2	F-statistic	0.31058	Prob. F(17,3)		0.951	Yes
	Obs*R-squared	13.39118	Prob. Chi-Square(17)		0.7096	Yes
	Scaled explained SS	0.492774	Prob. Chi-Square(17)		1.0000	

4 Model Stability Test:

The CUSUM and CUSUM of Squares tests were utilized to assess the stability of model parameters over the sample period. Both tests rely on recursive residuals to evaluate whether the estimated parameters remain stable or exhibit structural changes.

The CUSUM and CUSUMQ tests were conducted to evaluate the stability of the Model 2 having incorporated interactive dummy variable of the regressors into model 1 to address the structural break observed in 2010.

The CUSUM plot in Fig. 6 remained within the 5% critical lines throughout the sample period, indicating stable model parameters and no structural instability. Likewise, the CUSUMQ plot 7 stayed within the 5% critical bounds, confirming the absence of variance instability. These results suggest that the inclusion of the dummy variable for the year 2010 effectively resolved the structural break, enhancing the model's reliability and stability over time.

The model’s stability has significant implications for the robustness of the findings. It demonstrates the model's capability to accurately capture the dynamics between natural gas production and economic growth, even in the presence of structural shifts. This strengthens the validity of the model’s estimations, ensuring that the conclusions drawn are statistically sound. Furthermore, resolving the structural break improves the model’s applicability for policymaking and forecasting, as it adheres to the critical assumption of parameter constancy in time-series econometric analyses.

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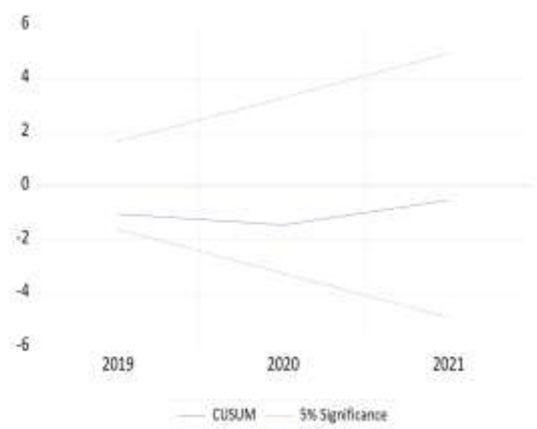

Figure 6 CUSUM stability test for Model 2

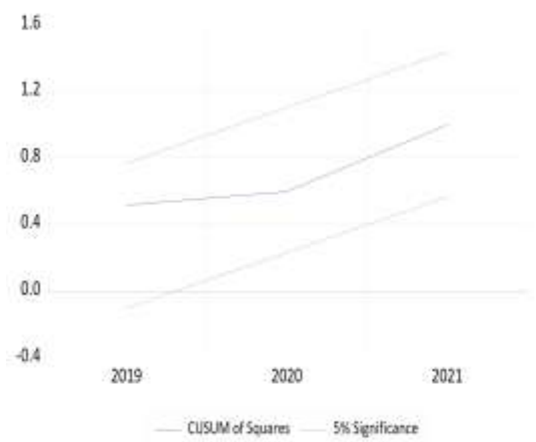

Figure 7 CUSUMQ stability test for Model 2

5 Empirical validation of the Model'sGoodness of Fit

To empirically validate the inclusion of dummy variables in addressing structural breaks, the models were compared: the model without dummy variables, as in Equation 5 (Model 1), and the model incorporating interactive dummy variables, as in Equation 6 (Model 2). This is shown in Table 8.

Model 1 demonstrates a strong fit with an R-squared of 0.8601, indicating it explains 86% of GDP variation. However, it assumes a single structural break in 2010, which limits its ability to capture evolving post-policy dynamics. The Adjusted R-squared of 0.8354 and AIC (-2.6417) suggest a decent model. However, additional refinements could enhance its explanatory power, while Model 2 significantly improves upon Model 1, with a high R-squared of 0.9970, capturing 99.7% of the variation in GDP. This model incorporates dummy variables to account for the 2010 structural break, which better reflects the evolving dynamics in Nigeria's gas sector. The Adjusted R-squared of 0.9946 and lower AIC (-5.9172) confirm Model 2's superior fit and efficiency, providing a more accurate and comprehensive representation of Nigeria's economic dynamics in response to the 2010 structural changes in the gas sector.

Table 8 Model Fitness Comparison Metrics for Dummy Variable Validation

Metric	Model 1 Without Dummy Variables	Model 2 With Dummy Variables
R-squared	0.8601	0.9970
Adjusted R-squared	0.8354	0.9946
Akaike Information Criterion (AIC)	-2.6417	-5.9172

Empirical Result

1. Short-Run Dynamics and Adjustment Speed

Tables 9 and 10 show the short-run ECM Regression equation results for the two ARDL models.

Examining the short-run coefficients, Model 2 demonstrates a more comprehensive representation of the dynamic effects of gas production, FDI, and structural changes in Nigeria's economy. The coefficient of gas production (D(LOG_GAS_PROD)) in Model 2 is positive and highly significant (0.2224, p = 0.0044), indicating that short-run variations in gas production strongly influence GDP growth. In contrast, Model 1 does not include gas production as a short-run determinant, potentially limiting its ability to capture the immediate economic effects of gas sector fluctuations.

Foreign Direct Investment (D(LOG_FDI)) in Model 2 also has a strong positive and significant impact on GDP growth (0.7281, p = 0.0002), whereas Model 1 does not account for FDI in the short run. Additionally, Model 2 identifies a structural break effect in FDI through the interaction term D(LOG_FDI_2010), which is negative and significant (-0.6372, p = 0.0002). This suggests that post-2010, the contribution of FDI to economic growth declined significantly, potentially due to policy shifts, external investment shocks, or global market conditions. Model 1, by contrast, does not capture this shift explicitly, reinforcing the view that it may overlook critical structural dynamics.

The error correction term (CointEq(-1)) in Model 2 is larger in magnitude (-2.9752, p = 0.0002) than in Model 1 (-0.1346, p = 0.0001), indicating that deviations from the long-run equilibrium correct much faster in Model 2. Specifically, about 297.5% of disequilibrium is adjusted within one year in Model 2, compared to only 13.5% in Model 1. This suggests that Model 2 captures a more responsive economic adjustment process, whereas Model 1 reflects a sluggish correction mechanism, which may not accurately represent Nigeria's economic dynamics post-2010.

Table 9 Short Run Result for Model 1

ECM Regression for Model 1				
Case 3: Unrestricted Constant and No Trend				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	-1.052844	0.199013	-5.290335	0.0001
D(LOG_GFCF)	0.213351	0.089074	2.39521	0.0324

D(LOG_IND_OUT)	0.406045	0.113461	3.57871	0.0034
CointEq(-1)*	-0.134618	0.024313	-5.536884	0.0001

Table 10 Short Run Result for Model 2

ECM Regression for model 2				
Case 5: Unrestricted Constant and Unrestricted Trend				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	4.368442	0.190652	22.91321	0.0002
@TREND	0.241553	0.011317	21.34513	0.0002
D(LOG_GAS_PROD)	0.222369	0.028517	7.797649	0.0044
D(LOG_FDI)	0.728084	0.033453	21.7643	0.0002
D(LOG_GFCF)	-0.076409	0.020701	-3.691025	0.0345
D(LOG_IND_OUT)	0.361128	0.036374	9.928208	0.0022
D(DUMMY_2010)	3.724853	0.240186	15.5082	0.0006
D(LOG_FDI_2010)	-0.637186	0.030167	-21.12207	0.0002
D(LOG_GFCF_2010)	1.117569	0.067913	16.45579	0.0005
CointEq(-1)*	-2.975248	0.134	-22.20333	0.0002

Long-Run Relationships and Structural Shifts

Tables 11 and 12 show the results of the long-run levels equation of the two ARDL models. The long-run coefficients in Model 2 suggest that gas production has a statistically significant positive impact on GDP growth (0.1580, p = 0.0368). In contrast, in Model 1, gas production is included but is statistically insignificant (1.3888). This finding underscores the advantage of Model 2, which isolates structural changes using dummy variables rather than imposing a single structural break that may dilute the effect of gas production over time.

Table 11 Long run Result for Model 1

Levels Equation for Model 1				
Case 3: Unrestricted Constant and No Trend				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LOG_GAS_PROD	1.388757	1.159919	1.197288	0.2526
LOG_FDI	0.291455	0.2682	1.086708	0.2969
LOG_GFCF	0.29706	0.645092	0.460493	0.6528
LOG_IND_OUT	-0.642661	1.473354	-0.436189	0.6699
EC = LOG_GDP - (1.3888*LOG_GAS_PROD + 0.2915*LOG_FDI + 0.2971 *LOG_GFCF -0.6427*LOG_IND_OUT)				

Additionally, the interaction term LOG_GAS_PROD_2010 in Model 2 is negative (-0.2154, p = 0.0766), implying that the post-2010 impact of gas production on GDP weakened. This result suggests that factors such as regulatory changes, shifts in global gas markets, or domestic economic challenges may have altered the effectiveness of gas production in driving growth. Model 1 does not explicitly capture this post-2010 shift, reinforcing the view that its structural break approach is less effective in identifying nuanced economic changes.

Similarly, capital formation (GFCF) plays a key role in Model 2. While its overall long-run effect is statistically insignificant (0.2397, p = 0.1865), the interaction term LOG_GFCF_2010 is positive and highly significant (0.6147, p = 0.0011). This suggests that after 2010, capital formation contributed more substantially to GDP growth, possibly due to increased infrastructure investments, policy reforms, or economic diversification efforts. Model 1, which does not include interaction terms, overlooks this critical finding.

In conclusion, the findings indicate that structural breaks significantly influence the relationship between natural gas production and economic growth in Nigeria. While Model 1 provides some evidence of a long-run relationship, its inability to capture post-2010 structural shifts limit its explanatory power. Model 2, which incorporates interactive dummy variables, offers a more comprehensive and statistically robust framework. It confirms strong cointegration and reveals the evolving impact of gas production, FDI, and capital formation. Therefore, Model 2 is the preferred model for assessing structural breaks in the gas-GDP nexus, as it provides deeper insights into Nigeria's economic transformation and policy implications post-2010.

Table 12 Long Run Result for Model 2

Levels Equation for Model 2				
Case 5: Unrestricted Constant and Unrestricted Trend				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LOG_GAS_PROD	0.15802	0.043905	3.599147	0.0368
LOG_FDI	0.426933	0.040804	10.46314	0.0019
LOG_GFCF	0.23972	0.140482	1.706417	0.1865
LOG_IND_OUT	0.019829	0.080387	0.246671	0.8211
DUMMY_2010	0.525584	0.884408	0.594278	0.5942
LOG_GAS_PROD_2010	-0.215404	0.081111	-2.655679	0.0766
LOG_FDI_2010	-0.332732	0.062527	-5.321426	0.013
LOG_GFCF_2010	0.614721	0.049347	12.45716	0.0011
EC = LOG_GDP - (0.1580*LOG_GAS_PROD + 0.4269*LOG_FDI + 0.2397*LOG_GFCF + 0.0198*LOG_IND_OUT + 0.5256*DUMMY_2010 -0.2154*LOG_GAS_PROD_2010 -0.3327*LOG_FDI_2010 + 0.6147 *LOG_GFCF_2010)				

V. DISCUSSION OF RESULTS

Economic Implications in Evaluating Structural Breaks in the Natural Gas-GDP Nexus

The results from the ARDL Estimation have significant economic implications for understanding how structural changes, particularly the implementation of the Nigeria Gas Master Plan (NGMP) and the Niger Delta Amnesty Program (NDAP) in 2010, have shaped the relationship between natural gas production and economic growth in Nigeria. The comparison between Model 1, which was impacted by a structural break in 2010, and Model 2, which isolates the structural break effects using dummy variables, provides key insights into how gas sector reforms, investment patterns, and institutional changes have influenced GDP growth.

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The F-bounds test results suggest that a long-run relationship exists between gas production and economic growth, but Model 2 provides stronger statistical evidence of cointegration than Model 1. This suggests that incorporating structural break effects through dummy interactions (Model 2) offers a more reliable representation of Nigeria's economic reality than a model influenced by a single break in 2010.

The long-run coefficients indicate that gas production significantly and positively impacts GDP in Model 2 but is not statistically significant in Model 1. This suggests that the Nigeria Gas Master Plan and the Niger Delta Amnesty Program had complex and evolving impacts on economic growth. While these policies aimed to boost gas investment and stabilize the Niger Delta, their effects were not uniform over time. The long-run positive impact of gas production in Model 2 implies that over time, reforms in the gas sector contributed to economic expansion, likely through increased gas utilization, enhanced industrial capacity, and improved energy security.

However, the negative interaction term (LOG_GAS_PROD_2010) in Model 2 suggests that post-2010, gas production's contribution to GDP growth weakened. This could reflect challenges such as infrastructural bottlenecks, regulatory hurdles, and global energy price fluctuations that may have slowed the expected benefits of gas sector reforms. The lack of this interaction effect in Model 1 means that due to the structural break,the modelfails to capture gas sector policies' gradual and dynamic impact on economic growth.

In the short run, Model 2 shows that gas production significantly influences GDP growth, whereas Model 1 does not explicitly capture gas production in the short-run dynamics. This highlights an important economic insight:In Nigeria, fluctuations in gas production have immediate economic consequences, possibly due to their impact on industrial energy supply, export earnings, and fiscal revenues. The omission of this effect in Model 1 suggests that a rigid structural break effect underestimates the short-run responsiveness of the economy to changes in gas production.

Foreign Direct Investment (FDI) plays a crucial role in the short-run growth process, with a significant positive impact in Model 2. However, the interaction term D(LOG_FDI_2010) is negative, indicating that after 2010, the influence of FDI on GDP growth declined. This could be attributed to investment uncertainties, regulatory risks, or investor confidence shifts following the NGMP implementation and post-amnesty adjustments. The Niger Delta Amnesty Program aimed to reduce conflict and encourage investment, but lingering security risks, policy inconsistencies, and macroeconomic instability may have constrained the anticipated FDI-led growth. Model 1 does not capture these post-2010 FDI effects, weakening its explanatory power.

The role of Gross Fixed Capital Formation (GFCF) is also noteworthy. Model 2 reveals that post-2010, the effect of capital formation on GDP growth became stronger, as indicated by the positive and highly significant interaction term D(LOG_GFCF_2010). This suggests that gas infrastructure investments and broader economic reforms post-2010 began to yield growth benefits over time. The inability of Model 1 to differentiate between pre-2010 and post-2010 capital formation effects limits its policy relevance, as it assumes a uniform structural break rather than recognizing how investment impacts evolved.

The error correction term (CointEq(-1)) in Model 2 is significantly larger in magnitude (-2.9752) than in Model 1 (-0.1346), indicating that deviations from long-run equilibrium correct at a much faster rate in Model 2. This has important economic implications. The slow adjustment in Model 1 suggests that when GDP deviates from its long-run path, it takes longer for the economy to return to equilibrium. This implies that Model 1 underestimates economic flexibility and GDP's responsiveness to policy changes. In contrast, Model 2 shows that the Nigerian economy is highly responsive to shocks and structural changes, meaning policymakers can expect quicker economic stabilization when implementing reforms in the gas sector.

VI. CONCLUSION

This study highlights the critical role of structural breaks in shaping the relationship between natural gas production and economic growth in Nigeria. The superior performance of Model 2, which incorporates dummy variables for the 2010 gas sector reforms, underscores the need to account for policy-induced shifts in economic analysis. The findings confirm that reforms such as the Nigeria Gas Master Plan (NGMP) and the Niger Delta Amnesty Program (NDAP) significantly influenced the sector's contribution to economic growth.

Policy measures should prioritize strengthening Nigeria's gas infrastructure while mitigating economic disruptions from structural changes. First, full implementation of the NGMP is essential, focusing on gas transportation, domestic utilization, and flare reduction to maximize economic benefits. Second, policy adjustments should be phased in gradually to minimize economic volatility. Third, further investments in gas infrastructure should be encouraged through incentives for private sector participation. Lastly, economic diversification strategies should be reinforced to reduce overdependence on the oil and gas sector.

Further research should explore the long-term effects of gas sector reforms using higher-frequency data and advanced econometric techniques, such as nonlinear models, to capture dynamic shifts. Additionally, examining the interaction between gas sector investments and Nigeria's transition to renewable energy is crucial. Finally, A comparative analysis with other resource-rich economies could provide insights into the broader applicability of these findings.

In conclusion, accounting for structural breaks is essential for accurately assessing the gas-growth nexus in Nigeria. Policymakers should integrate these insights to design strategies that support sustainable growth. Future studies should refine these findings by exploring additional economic dimensions and cross-country comparisons to deepen understanding of the gas sector's transformative potential.

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